DEVELOPMENT OF SHORT TERM HYDROSTATIC TEST FOR PVC PIPES

MOHAMAD NABIL BIN NOR AZMAN

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ABSTRACT

This thesis deals with experimental design for the short term hydrostatic test for the Polyvinyl Chloride (PVC) pipes. The objective of this thesis is to design or develop an experimental setup in determining the burst pressure of a PVC pipes by the means of internal pressure. The thesis describes the experimental procedures to determine the burst pressure of the PVC pipes. The experimental value obtained is then compared to the theoretical value calculated from an existing formula. The samples used are designed using computer aided software which is SolidWork. The samples are then fabricated and tested based on the setup designed. From the result obtained, the value of experimental burst pressure is indeed different from the theoretical burst pressure.The result is then compared again with other formula basely for metal pipes in order to check the validity of the equations to be used for PVC pipes. Based on the result, the equations are not too suitable to be used as the different between the values from the main equation with the values calculated from other standard are too big. The result obtained from the experiment setup is also consistence as thus making a possible design to be proposed to the Department of Malaysian Standard as one of the test for the short term hydrostatic test in MS 628 standard.

ABSTRAK

Tesis ini membentangkan rekaan eksperimen untuk ujian hidrostatik jangka pendek untuk paip jenis PVC. Objektif yang perlu dicapai oleh kajian tesis ini adalah untuk mereka atau mencipta satu eksperimen yang boleh digunakan untuk mendapatkan tekanan yang boleh memecahkan paip PVC dengan cara memecahkannya dari dalam. Di dalam tesis ini juga terdapat prosedur–prosedur yang perlu diikuti untuk mendapatkan tekanan tersebut. Tekanan yang diperolehi melalui eksperimen ini kemudiannya akan dibandingkan dengan tekanan yang diperoleh melalui kiraan menggunakan formula yang sedia ada untuk melihat perbezaan di antara kedua-duatekanan. Melalui perbandingan ini kita dapat lihat yang tekanan yang didapatkan melalui eksperimen adalah lebih tinggi berbanding tekanan yang didapatkan melalui kira-kira menggunakan formula. Tekanan yang didapatkan melalui kira-kira kemudiannya akan dibandingkan lagi dengan tekanan yang diperoleh melalui formula-formula lain yang lebih sesuai untuk paip besi. Hal ini adalah untuk melihat kesesuaian formula tersebut untuk digunakan untuk paip PVC.Melalui perbandingan ini kita boleh katakan yang formula tersebut tidak sesuai kerana perbezaan tekanan itu agak besar. Selain itu, keputusan yang diperoleh melalui eksperimen ini agak konsisten dan ini membolehkan rekaan eksperimen ini dihantar ke badan yang mengawal standard di Malaysia seperti SIRIM untuk dimasukkan ke dalam standard MS 628 sebagai rekaan eksperimen untuk ujian hidrostatik jangka pendek.

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LIST OF SYMBOLS

Dm_{min}	Minimum outside diameter
T_{min}	Minimum wall thickness
s	Circumferential hoop stress
d	Maximum depth of defect
c	Maximum width of the defect
l	Maximum length of the defect
D	Outside diameter of pipe
σ_y	Yield strength
M	Folias Factor / Bulging stress
σ_f	Flow stress

LIST OF ABBREVIATIONS

AWWA	American Water Works Association
ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineers
BS	British Standard
cPVC	Chlorinated Polyvinyl Chloride
DNV	Det Norske Veritas
DSM	Department of Standards Malaysia
EDC	Ethylene Dichloride
FEM	Finite Element Method
MS	Malaysian Standard
PVC	Polyvinyl Chloride
SIRIM	Standards and Industrial Research Institutes of Malaysia
UKWIR	United Kingdom Water Industry Research
uPVC	Unplasticized Polyvinyl Chloride
USA	United States of America

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

PVC or Polyvinyl chloride is one of the materials which had been widely used plastic throughout the world nowadays aside from polyethylene and polypropylene. From the usage in supplying water for domestic and industrial used to the transferring of waste materials either in form of liquids (chemicals) or gas. The global demand for PVC pipes nowadays had increased 4.6 percent annually through 2012 to 8.2 billion meters or 18.2 million metric tons (The Freedonia Group, 2009). However, the usage of PVC pipes in piping throughout Malaysia is still about only 10 percent compared to the 60 to 70 percent of PVC pipes global usage (Bernama, 2008). PVC pipes can be divided into two which are unplasticized PVC (uPVC) and chlorinated PVC (cPVC). This research paper will go deeply in the experimental design in obtaining the burst pressure of a uPVC straight pipe. The experiment will more toward short term hydrostatic test. The final design of the experiment will then be proposed to the Department of Standards Malaysia as the design of experiment to test the PVC pipes in terms of short term hydrostatic test. This experiment will only test the capability of the MS 628 pipes which is the PVC pipes used in the water supply, Department of Standards Malaysia (DSM, 1999). This experiment will also compare the result obtained from a perfect straight pipe and the pipe with defect on it. The only defect used in this study is gouge. The other defects such as crack are not used because it is hard to produce a control-sized of a crack. Apart from that, corrosion is not suitable as plastic material such as PVC is resistant against corrosion, flexible, and easy to handle (Farshad, 2006).

1.2 STATEMENT OF PROBLEMS

Polyvinyl chloride pipes or PVC pipes are widely used as a medium to supply water to house and to the industry. The process of transferring the water from the reservoir to the customers is involved the pumping of water into the pipes. Hence, making the pressure inside the pipes increased and this has also increased the risk of the pressure to exceed the burst pressure of the pipes. The value of the burst pressure varies among the PVC pipes as they have different thickness, size of nominal diameter and also standard. Although the standards either Malaysian Standard (MS) 628, British Standard (BS) 3505 or even American Standard Testing and Material (ASTM) D1784 - 11 has stated the example of method that can be used to measure amount of internal pressure that can be withstand by the pipes but however, the actual pressure will always be different compared to the theoretical value. Therefore, this research will be focusing on showing the actual burst pressure of a perfect uPVC pipe and pipe with defect is lower or higher compared to the theoretical burst pressure of a perfect pipe and the one with defect in equation (1).

$$P_{burst,act} \neq P_{burst,theoretical} \quad (1)$$

The Department of Malaysian Standard is the one that that control all the standards used in Malaysia. MS 628, the standard and specifications for the unplasticized PVC (uPVC) pipes for water supply. However, there are no detail explainations on the method to perform the short term hydrostatic test although all the other test such as heat reversion test and long term hydrostatic test have detailed explaination in each step of the experiment including the samples. Besides that, as the usage of PVC pipes are not in a very critical area such as oil and gas, there are only a few researches in terms of the burst pressure of the PVC pipes.

1.3 OBJECTIVE

The objectives of this research are:

(i) To determine the burst pressure of a perfect straight pipes and the pipes with defects.
(ii) To compare the burst pressure obtained from the experiment with the theoretical value obtained from calculations.
(iii) To suggest a new design of experiment for the short term hydrostatic test for MS 628 pipes.

1.4 PROJECT SCOPES

The burst pressure test is run for the mean of determining the quality of the pipes and also to find the remaining strength of the pipes when a defect is introduced to the pipes. The burst pressure test however must be referring to specifications to either three of the specifications recognized in Malaysia which are the MS 628, BS 3505 and ASTM D1784 – 11. Following the specifications stated inside the report produced for MS 628 is the best as the idea to do this experiment is due to the absence of the design of experiment for the short-term hydrostatic test inside the MS 628 standard. The method of the experiment is to design the rig first. Then, all the materials are prepared and the rig is fabricated. The samples for the experiment is prepared following the specifications such as the length of the samples must be between 250 mm and 750 mm, Department of Standards Malaysia (DSM, 1999). The test will firstly determine the burst pressure of a perfect pipe and followed by the burst pressure for the pipe with the presence of defect. For this paper, the defect introduced will only be in form of gouge. The experimental result will then compared with the result acquired from the calculation. Then, analysis and discussion of the result is done and a conclusion is made based on the analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will provide the review on the title of the research with respect to the research produced by other people which is taken from the journal, article and books. The previous researches may use other defects such as creep and corrosion and compare the burst pressure that obtained either by experimentally, theoretically or using the Finite Element Analysis. This chapter will also discuss about the history behind polyvinyl chloride (PVC), the MS 628 pipes and the defects existed in the pipelines. This chapter will also discussed one the general review on PVC pipes in terms of mechanical properties and specifications on the PVC pipes present throughout the world these days.

2.2 STANDARD AND SPECIFICATION

All areas of study especially engineering are very delicate when involving the standard of requirements for a materials. Every material had their own standard and specifications and this include PVC pipes as well. Almost every continent in the world had a standard to be follow and Malaysia is one of the countries that had their own standard although the standard is derived from other country's standard. The Malaysian Standard (MS) is derived from the British Standard (BS). United States of America (USA) also have their own standard called American Society for Testing and Materials or ASTM.

In Malaysia, the department that responsible in updating the standards is Department of Standards Malaysia (DSM). They are responsible in approving and giving accreditation of a new standard. DSM has appoints Standards and Industrial Research Institutes of Malaysia (SIRIM Berhad) as an agent to improve and produce the standard. SIRIM is also responsible in distributing and selling the Malaysian Standard. There will be a committee formed every time a new standard is proposed. The committee is made of professionals such as engineers either from SIRIM or other companies, consumers such as owner of companies and also users. The number of representative inside a committee is balanced for each group.

The PVC pipes are produced by the factories according to the standards and specifications produced by the Department of Standards Malaysia (DSM) such as MS 628 and MS 762. The pipes that I am using for my research now are the pipes that under the specifications released under the standard MS628. MS628 is derived from British Standard (BS) 3505:1986 which is the standard for transferring cold potable water or supplying water. This standard is for uPVC pipes only. This standard is be divided into three parts; Part 1 is about pipes, Part 2 is about joints and fittings for use with unplasticized PVC pipes while Part 3 is about the guide to install the pipes. Part 2 is divided into two subdivisions; the first part is about uPVC joints and fittings while the second part is about solvent cement. For industrial uses, the specifications can be seen inside the paper for Malaysian Standard (MS) 762. This specification is taken from BS 3506. The standards and specifications released by the SIRIM Berhad already stated the entire required test that crucial in order for straight pipes and also the joints and fittings to be approved as a good product. The tests are:

(i) Heat reversion test
(ii) Resistance to acetone test
(iii) Impact strength test
(iv) Short term hydrostatic test
(v) Long term hydrostatic test
(vi) Fracture toughness test

(vii) Opacity test

(viii) Effect of materials on water quality

However, the report is lack of the design of the experiment for the short term hydrostatic test. The report only stated the specifications for the experiment to be valid but did not proposed the design of experiment that can be used in order to check the hydrostatic pressure of the uPVC pipes. Therefore, one of my objectives is to design an experiment for the short term hydrostatic test and if possible, proposed it to the SIRIM. There are many defects on PVC pipes that may lead to the failure of the pipes but the one that been introduced to the pipes during the experiment is gouge defect as shown in Figure 2.1.

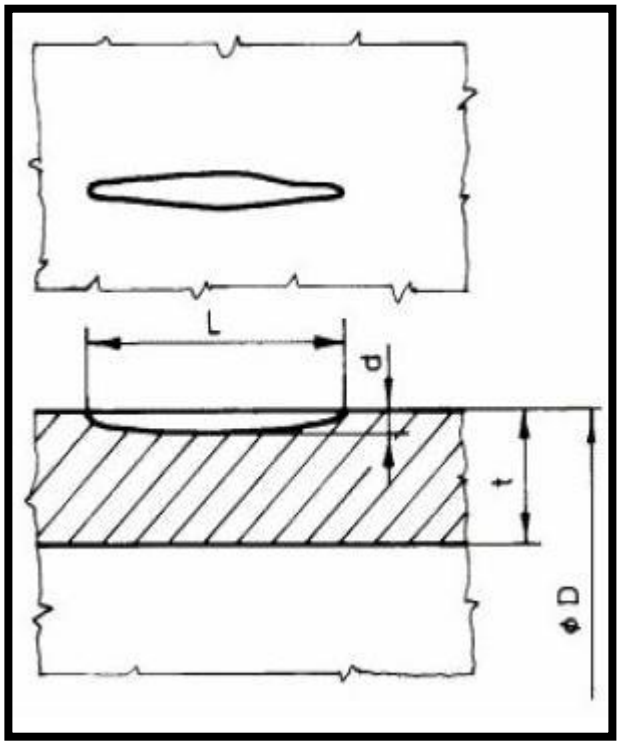

Figure 2.1: Gouge defect

Source: Dr Abdel-Alem (2000)

2.3 POLYVINYL CHLORIDE (PVC)

2.3.1 General on PVC

Plastic industry had actively increased in numbers in 1940s but only in 1970 the use of plastic in engineering material had really step up (Edwards, 1998). The end of the nineteenth century is the time where two of the newly found industry which are the acetylene and chlorine industry facing overproduction. Hence, scientists that lived during that time had to struggle to find a new product that can be formed by forming the two products and PVC is the surfaced. PVC is generally accepted to be discovered in 1912, the same year a production process of PVC is reported (Mulder and Knot, 2008). When the PVC was firstly introduced, the materials are said to be brittle and degraded when exposed to heat and lights.

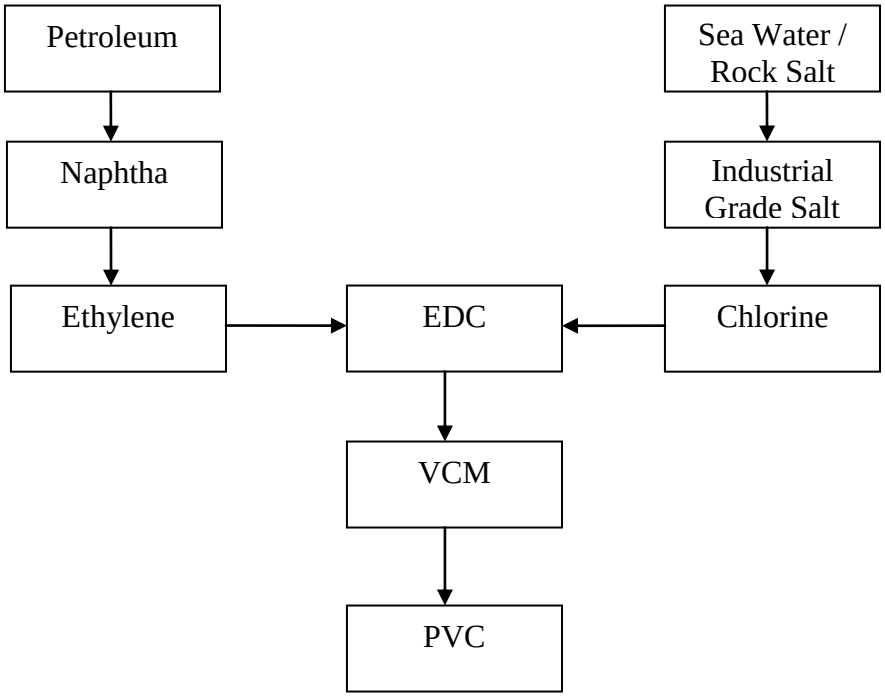

Figure 2.2: Flow chart in the production of PVC

Source: www.pvc.org

From the above Figure 2.2, the production of PVC is started from petroleum refining industry and salt industry. The naphtha produced is then processed to become ethylene while the salt will go through electrolysis to produced caustic soda and chlorine. Both ethylene and chlorine will then be combined to become EDC or ethylene dichloride before being processed to become vinyl chloride and finally become polyvinyl chloride or PVC.

2.3.2 PVC Pipes

Figure 2.3: PVC pipes

Source: www.all-about-pipe.com

PVC pipes as shown in Figure 2.3 are the most common materials that presence in the piping system nowadays. The characteristic of the PVC material which is chemically resistance allows it to be used as industrial piping system for waste disposal especially chemical and toxic wastes. PVC pipes are also been used to supply water for domestic and industrial used. However, the standard and specifications for each purpose are different in order to preserve the longevity of the pipes used. This is because different standard had

different physical and mechanical properties. As examples the PVC pipes used for the potable of water domestically are different from the PVC pipes used in industry. The strength and durability between the pipes are different as the pipes used in industrial area can withstand higher pressure than the pipes used for supplying water. PVC pipes are actively used to replace steel pipes in every area including sewage and water supply due its chemically resistant, low cost and easy to join the pipes. Advantages of PVC pipes in piping system are:

(i) Corrosion resistance
(ii) Chemical resistance
(iii) Low thermal conductivity
(iv) Flexibility
(v) Low friction loss
(vi) Lightweight
(vii) Variety of joining method
(viii) Weather resistance (Chasis, 1998)

PVC pipes can be divided into three types which are normal PVC, unplasticized polyvinyl chloride (uPVC) and chlorinated polyvinyl chloride (CPVC). Nowadays, uPVC is the pipes used in supplying water for domestic and industrial used. CPVC is one of the latest PVC pipes family that contains high amount of chlorine compared to PVC and uPVC. PVC pipes are recognized by their colour. Each colour represents different uses. The colour and their uses are as shown in Table 2.1:

Table 2.1: PVC pipes' colour and their uses

Colour	Uses
Blue	Water main
Red	Fire main
Purple	Reclaimed water main
Green	Sanitary sewer and forcemain
White	All applications
Orange	Telecommunications
Grey	Electrical conduit
Yellow	Gas distribution

Source: www.all-about-pipe.com

Plastic pipes not only lose their strength when exposed to high temperature, but also when exposed to low temperature (Cruz et al., 2010). CPVC pipes are then introduced as a solution for supplying high temperature of water. CPVC is a material produced by adding more time to the chlorination process and this postchlorination allows the material to has extended maximum service temperature from 21°C to 99°C (Chasis, 1998). CPVC pipes are then used as a medium for transferring hot water as the additional chlorine reduces the pipes' reaction to heat as cPVC had higher strength when experiencing high temperature compared to PVC and uPVC pipes that had their strength reduced. Table 2.2 below shows the dimensions of uPVC available in markets nowadays:

Table 2.2: The dimensions of uPVC available in markets

Nominal Size	Outside Diameter		Wall Thickness							
			Class B (6 Bar)		Class C (9 Bar)		Class D (12 Bar)		Class E (15 Bar)	
Inch	Min. mm	Max. mm	Min. mm	Max. mm	Min. mm	Max. mm	Min. mm	Max. mm	Min. mm	Max. mm
½	21.2	21.5							1.7	2.1
3/4	26.6	26.9							1.9	2.5
1	33.3	33.8							2.2	2.7
1.1/4	42	42.5					2.2	2.7	2.7	3.2
1.1/2	48	48.5					2.5	3	3.1	3.7
2	60	60.7			2.5	3	3.1	3.7	3.9	4.9
3	88.4	89.4	2.9	3.4	3.5	4.1	4.6	5.3	5.7	6.6
4	113.7	114.9	3.4	4	4.5	5.2	6	6.9	7.3	8.4
5	139.4	141	3.8	4.4	5.5	6.4	7.3	8.4	9	10.4
6	167.4	169.1	4.5	5.2	6.5	7.6	8.8	10.2	10.8	12.5
8	218	220.2	5.3	6.1	7.5	9	10.3	11.9	12.6	14.5
10	271.6	274.4	6.6	7.6	9.7	11.2	12.8	14.8	15.7	18.1
12	332.2	325.5	7.8	9	11.5	13.3	15.2	17.5	18.7	21.6
14	353.7	357.3	8.5	9.8	12.6	14.5	16.7	19.2		
16	404.3	408.5	9.7	11.2	14.5	16.7				

Source: www.epco-plastics.com

2.3.3 Physical and Mechanical Properties of PVC Pipes

PVC is a thermosetting plastic or in other word, it can only be molded and formed once. The action of molded and formed for the second time will lead to the loss of some of the important characteristics. The properties of PVC vary according to the steps in making it. This is because sometimes there are the presences of additives to the PVC in order to increase the strength and durability of the PVC material. Additives such as plasticizers, impact modifiers, processing aids, fillers, lubricants and stabilizers play an important role

in the structural strength of the PVC materials. The morphology of the resin particle of polyvinyl chloride is complex that the physical and mechanical properties of the PVC can be affected due to the changes at the degree of fusion. Moreover, both physical and mechanical properties of the PVC can be affected by free volume, crystallinity and orientation (Yarahmadi et al., 2003). The addition of plasticizers such as low-molecular-weight plasticizers decreases some of the mechanical properties such as hardness, modulus and tensile strength. However, it also improved the low-temperature flexibility, elongation and the ease of processing of the PVC [Pita et al., 2002). Table 2.3 showed the mechanical characteristics of a uPVC pipe.

Table 2.3: Mechanical properties of uPVC pipes

Property	Unit	Value
Density	Kg/m^3	1400 – 1460
Tensile Strength	MPa	45 – 50
Elongation	%	80 – 150
Compressive Strength	MPa	59
Modulus of Elasticity	MPa	3000
Specific Heat Capacity	kJ/kg.K	240
Linear Expansion	mm/m/°C	0.08
Volume Resistivity	Ohm/cm	10^{15}
Flammability	Self extinguish	Self extinguish

Source: www.hedley-international.com

In order to obtain all the mechanical properties such as the tensile strength and modulus of elasticity, tests such as a tensile test is done. The test is done following the ASTM D638 and the workpiece used follow the standard given in ASTM D882. The example of the workpiece is like thin film and sheets such as shown by Figure 2.4 below. For test to find elongation, the method used will follow the standard and specification which had been stated inside the standard ASTM D4551 – 12. The example of test method for elongation according to ASTM D4551 - 12 is also a tensile test.

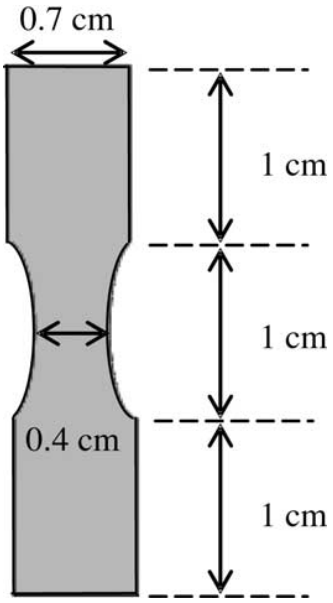

Figure 2.4: Tensile test specimen

Source: Rie et al. (2005)

2.4 BURST PRESSURE

Burst pressure is sometimes defined as the point at which something such as a valve or hose will fail as a result of pressure, and it may also be defined as the point right before failure will occur. In either case, burst pressure could be considered an expression of the maximum pressure which something can endure before it will break. It is important to consider burst pressure when designing any sort of system which is used with pressured materials such as water, gas, and various fluids, whether that system is the radiator in a car or a municipal water system.

A number of factors can influence burst pressure. Knowing the parameters, an engineer can calculate burst pressure and work backwards to determine which kinds of components could be used. Example of calculation that can be used to predict the burst pressure due to internal pressure is Barlows Equation that had been used by the industry for years. Obviously, one major factor is the material being used to make a valve, pipe, or